Missionary Ridge Wildfire Rehabilitation

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Abstract

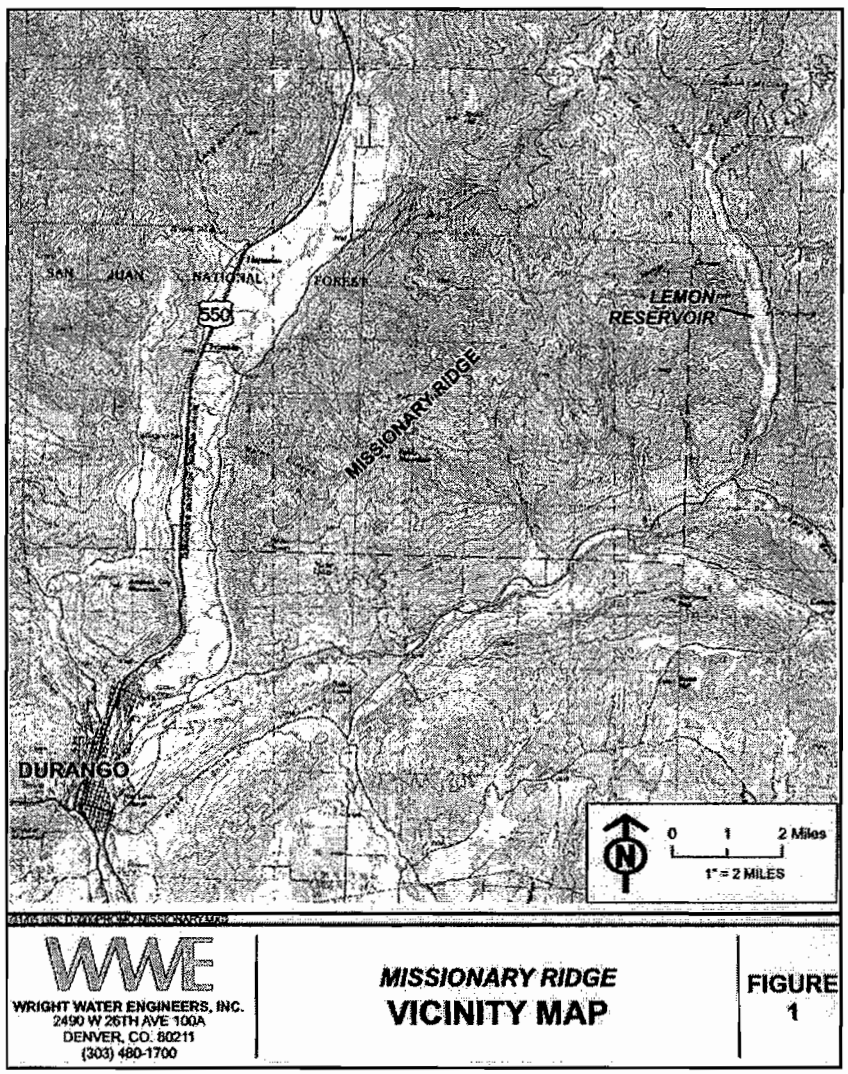
The Missionary Ridge wildfire of 2002 burned more than 28,000 hectares (ha) (70,000 acres [ac]) near Durango, Colorado. Risks posed by increased runoff and sediment and debris flow potential were widely recognized, prompting implementation of rehabilitation measures in many areas that had burned. This paper describes the successful implementation of rehabilitation measures by the Florida Water Conservancy District (FWCD) with the assistance of Wright Water Engineers, Inc. (WWE) in the Knight Canyon and South Drainage watersheds. The watershed is located above the spillway of the Lemon Reservoir, consisting of 184 ha (454 ac), over half severely burned in the wildfire. FWCD officials were concerned with the protection of the reservoir spillway from debris flows and the potential for heavy sediment loading to the Florida River and downstream water supply intakes. FWCD, with assistance from WWE, obtained a Section 319 grant through the Colorado Department of Public Health and Environment (CDPHE) for implementation of rehabilitation measures.

Rehabilitation measures implemented in the Knight Canyon and South Drainage watersheds included log erosion barriers (LEBs) over 93 ha (230 ac), at a density of 220 to 615 per ha (90 to 250 per ac) and 13 check dams and detention basins. These measures have been regularly maintained and repaired since they were installed. Five debris racks ranging in width from 5 to 14 meters (m) (15 to 47 feet [ft]) were installed along major drainage paths, and as of October 2003, had trapped nearly 150 cubic meters (m^3) (200 cubic yards [yd^3]) of debris. Other practices, including hand seeding of approximately 41 ha (100 ac) and mulching and hand crimping of 30 ha (75 ac) have proven effective. The effectiveness of the rehabilitation measures was truly put to the test when 6.27 centimeters (cm) (2.47 inches [in]) of rain fell over a 13-hour period on September 9, 2003. Runoff, sediment, and debris from the Knight Canyon watershed during this event were substantially less than from other comparably sized, nearby watersheds that had not received such extensive treatment.

This paper also provides an overview of the effects of the Missionary Ridge wildfire of 2002 on the Knight Canyon and South Drainage, a roughly 184-ha (454-ac) watershed adjacent to the spillway of the Florida Water Conservancy District's (FWCD's) Lemon Reservoir near Durango, Colorado. The paper describes: 1) the post-fire hydrologic assessment and analyses performed by WWE in conjunction with FWCD, 2) rehabilitation efforts by FWCD including measures implemented and sources of funding, 3) effectiveness of rehabilitation measures during rainfall events since the 2002 wildfire, and 4) "lessons learned" for future rehabilitation efforts.

Missionary Ridge Wildfire

The Missionary Ridge wildfire began on June 9, 2002 near Durango, Colorado, in the midst of a record-breaking drought, following yet another winter with less than average snow pack. Figure 1 is a vicinity map showing the City of Durango (City) and the Lemon Reservoir, located approximately 23 kilometers (km) (14.5 miles [mi]) northeast of the City. The Missionary Ridge wildfire burned more than 28,000 ha (70,000 ac), mostly in the San Juan National Forest (Wilderness Society 2003, Burned Area Emergency Rehabilitation [BAER] 2002). Figure 2 illustrates the extent of the Missionary Ridge wildfire (BAER 2002).



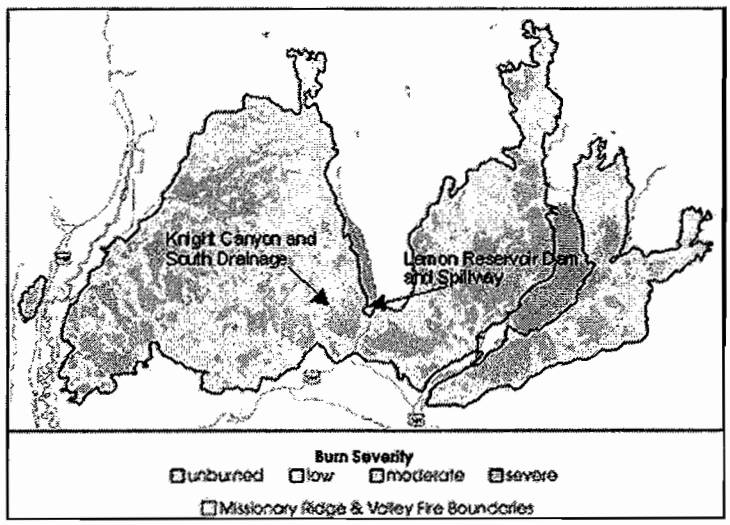


Figure 2. Extent and Burn Severity of 2002 Missionary Ridge Complex Wildfire (BAER 2002)

Eighty-three structures were lost, and suppression costs were nearly $40 million (Wilderness Society 2003). The Wilderness Society provided a summary of the Missionary Ridge wildfire in their March 2003 *Science and Policy Brief*:

> *The 2002 fire season was one of the biggest in the past half-century. By the end of the year, fires had burned across 7.2 million acres, costing of $1 billion to fight...The Missionary Ridge Fire began on June 9, 2002, apparently from a carelessly discarded cigarette...The fires occurred at the height of a record drought in southwestern Colorado, resulting from a low winter snow pack and only 1.3 inches of precipitation since the beginning of the year. Fuel moisture and relative humidity were among the lowest ever recorded.*

LEMON RESERVOIR AND FLORIDA RIVER

The Lemon Reservoir was constructed in 1963 and is operated by the FWCD under the direction of Superintendent John Ey. The reservoir is located at an elevation of approximately 2,490 m (8,167 ft) (dam crest) with a surface area of 252 ha (622 ac) and a maximum storage capacity of approximately 49.5 m^3 (40,146 acre feet [AF]). The watershed draining to the Lemon Reservoir consists of 180 square kilometers (km^2) (69 square miles [mi^2]) of steep, predominantly forested terrain. Soils in the watershed have hydrologic soil group (HSG) classifications ranging from B to D, with a majority of type C and D soils. Due to the forested nature of the watershed and the accumulation of forest litter and a substantial duff layer, potential for wildfire induced hydrophobicity was high. Wildfire impacts in the tributary watershed ranged from low to severe, with many of the most severe impacts concentrated in the sub-basins immediately adjacent to the reservoir spillway and stilling basin. The Knight Canyon (Photo 1), 146 ha (360 ac), with large areas of high burn severity, drains to Lemon Reservoir in close proximity to the spillway. Concerns with the Knight Canyon included structural safety of the spillway given potential for debris flow, quality of water stored in the reservoir, potential for significant debris

and sediment accumulation in the reservoir and interruption of reservoir operation. The South Drainage, immediately south of the Knight Canyon with an area of approximately 36 ha (90 ac), posed a potential threat to the reservoir stilling basin and the water quality of the Florida River. Photo 2 shows a view of the Knight Canyon and South Drainage after mulching was applied in the summer of 2003 from the dam crest.

Photo 1. Knight Canyon Looking Southeast Down at Spillway Entrance.

The Florida River is the primary source of drinking water for Durango. It also provides supplemental irrigation water to 7,871 ha (19,450 ac) of farmlands southeast of Durango. The Florida River originates approximately 42 km (26 mi) northeast of Durango in the San Juan Mountains and runs 80 km (50 mi) from the headwaters to the confluence with the Animas River. Impacts to the Florida River from the Missionary Ridge wildfire were substantial. Major tributaries including Shearer Creek and the Lemon Reservoir watershed upstream of a primary City water supply intake were severely burned, creating the potential for debris flows, dramatically increased sediment transport and impairment of the major drinking water source for a city with a population of roughly 14,700.

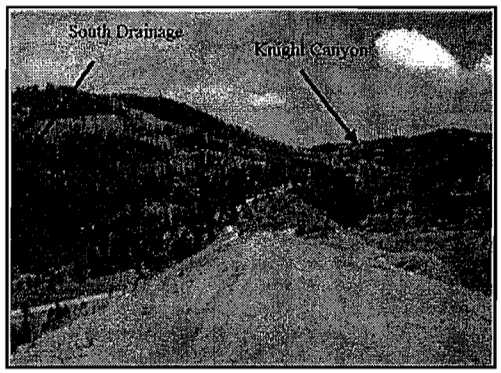


Photo 2. Knight Canyon and South Drainage from Lemon Reservoir Dam Embankment.

Post-Fire Hydrologic Assessment and Analyses

WWE began working with the FWCD and the City before the Missionary Ridge wildfire had been completely contained for expertise in post-fire hydrologic and hydraulic evaluations and analyses. WWE performed work at Mesa Verde National Park (MVNP) and at Los Alamos National Laboratory (LANL) in previous years following the Cerro Grande wildfire in Los Alamos and after a number of recent fires at MVNP, including the Bircher and Long Mesa wildfires. In addition, through the Wright Paleohydrological Institute (WPI), the authors have been examining wildfire impacts, rehabilitation, and recovery at MVNP since 1996. WWE applied experience with post-fire hydrology at these proximate sites to evaluate peak flow rate and runoff volumes immediately following the Missionary Ridge wildfire for the Knight and South Drainages. Table 1 summarizes burn areas for the Knight Canyon and South Drainage, and Figure 3 illustrates burn severity.

TABLE 1
KNIGHT CANYON AND SOUTH DRAINAGE AREAS AND BURN SEVERITY

Subbasin	Unburned (ha/ac)	Low (ha/ac)	Moderate (ha/ac)	Severe (ha/ac)	Total (ha/ac)
Knight	5/12	31/78	44/108	67/166	147/364
South	0/0	1/4	2/5	33/81	36/90
Total	5/12	32/82	46/113	100/247	183/454

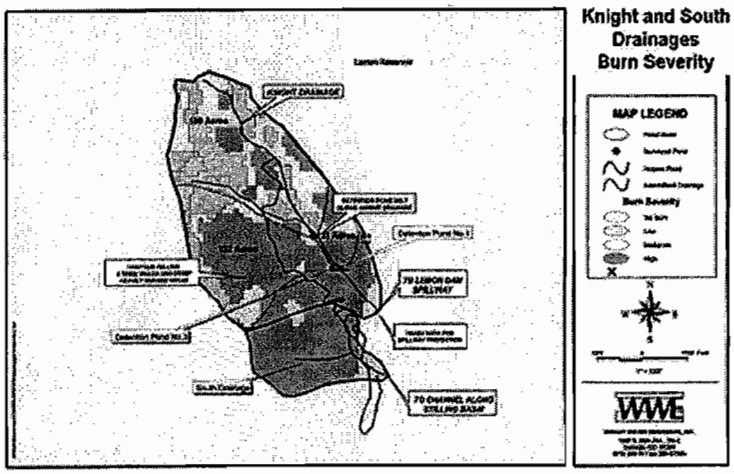


Figure 3. Burn Severity and Rehabilitation Measures for Knight Canyon and South Drainage.

WWE's hydrologic evaluation and analyses included the following elements:

1. Field reconnaissance including photographic documentation, soil sampling, hydrophobicity drop testing, canopy evaluation, identification of debris flow potential and other measurements and observations.
2. National Resource Conservation Service (NRCS) Curve Number (CN) evaluation of pre- and post-fire conditions including considerations for changes in ground cover and CN values due to burn severity, changes in initial abstractions, reduced infiltration potential, and watershed lag time. CN values selected were based on field observations and experience at other sites in the region including observations of gaged peak flow increases at LANL following the Cerro Grande wildfire in response to rainfall events that occurred during the summer of 2001 immediately following the fire. The NRCS CN approach was applied to estimate pre- and post-fire runoff volumes and peak flow rates because it is a method that can be rapidly applied based on data typically collected by the BAER team following wildfires. It is more appropriate than other physically based, but time consuming methods for situations where a rapid assessment is necessary due

to imminent risks to public health, safety and welfare as well as critical infrastructure such as the Lemon Reservoir.

Tables 2, 3, and 4 summarize CN, initial abstraction and lag time estimates; precipitation data for 2-, 10-, 25- and 100-year, 6-hour events; and hydrologic calculations based on the NRCS CN method.

TABLE 2
ESTIMATES OF PRE- AND POST-FIRE CURVE NUMBERS, INITIAL ABSTRACTIONS, AND LAG TIMES FOR THE NRCS CN METHOD

Subbasin	Curve Number		Initial Abstraction (cm/in)		Lag Time (hrs)	
	Pre-fire	Post-fire	Pre-fire	Post-fire	Pre-fire	Post-fire
Knight	60	76	3.38/1.33	0.56/0.22	1.4	0.9
South	60	82	3.38/1.33	0.08/0.03	0.4	0.2

TABLE 3
PRECIPITATION TOTALS FOR 6-HOUR STORM EVENTS

Return Interval (years), 6-hour Event	Total Precipitation (cm/in)
2	3.6/1.4
10	5.1/2.0
25	5.6/2.2
100	6.6/2.6

TABLE 4
PRE- AND POST-FIRE PEAK RUNOFF RATES AND VOLUMES FOR 6-HOUR STORM EVENTS

	Knight Drainage					
	Peak Flow (cms/cfs)			**Runoff Volume (m^3/AF)**		
Event	Pre-Fire	Post-Fire	Ratio	Pre-Fire	Post-Fire	Ratio
2-yr, 6-hr	0/0	2.07/73	N/A	0/0	120/10	N/A
10-yr, 6-hr	.23/8	4.19/148	19	2,470/2	23,440/19	10
25-yr, 6-hr	.37/13	5.01/177	14	3,700/3	28,370/23	8
100-yr, 6-hr	.82/29	6.77/239	8	7,400/6	38,240/31	5
	South Drainage					
2-yr, 6-hr	0/0	2.24/79	N/A	0/0	4,930/4	N/A
10-yr, 6-hr	.11/4	4.02/142	36	490/0.4	8,630/7	16
25-yr, 6-hr	.20/7	4.67/165	24	1,230/1.0	9,870/8	8
100-yr, 6-hr	.48/17	6.00/212	12	1,850/1.5	12,330/10	7

The results of hydrologic calculations for the Knight Canyon and South Drainage were relatively consistent with experiences at LANL, Mesa Verde, larger-scale BAER estimates, and other studies in the southwest (Buckley et al. 2002; Floyd-Hanna, et al. 2002; Floyd et al. 2002; U.S. Department of Interior 2002). These

estimates, more localized in nature than the BAER analysis, confirmed the concerns of FWCD for the safety of the Lemon Reservoir water quality, spillway, stilling basin and Florida River water quality. The response was a large-scale rehabilitation effort for the Knight Canyon and South Drainage.

Rehabilitation

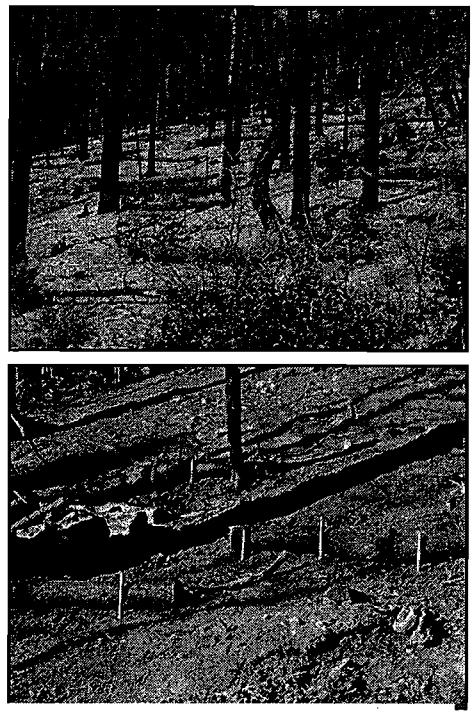
Soon after the BAER report was published, FWCD along with WWE worked to develop a plan to implement recommendations contained in the BAER report, as well as to develop additional Best Management Practices (BMPs) to provide a greater degree of protection to the intake, spillway, stilling basin, and general water quality of Lemon Reservoir and the Florida River. The burned area near Lemon Reservoir occurred primarily on private land; hence funding from traditional sources including the U.S. Forest Service and the Bureau of Reclamation was not available. So, the District looked elsewhere. They put up both cash and in-kind funds to help secure grants from the NRCS Emergency Water Protection (EWP) Program, as well as the Non-point Source Program of the CDPHE's Water Quality Control Division. This is the point where this rehab project really separated itself from other post-fire rehabilitation projects.

In August 2002, less than one month after the Missionary Ridge Fire was declared 100 percent contained, on-the-ground work to repair, protect, and reclaim the areas around Lemon Reservoir that had been hardest hit by the fire, had already begun. Work in Knight Canyon was identified as the highest priority, since the potential for debris flows from this canyon following a rain event constituted the most serious threat to the facilities and water supply. With smoke still smoldering from fallen trees, 13 rock and earth barrier check structures with overflow depressions were constructed in the canyon. These structures ranged from 6 to 18 m (20 to 60 ft) in length, and 1.5 to 2.5 m (6 to 8 ft) in height (Photo 3). To ensure these structures would perform as designed and to prevent "shock" loads as a result of debris flows and debris dams, all debris was removed from Knight Canyon.

Photo 3. Earth and rock check dam in Knight Canyon holding back sediment and debris after September 2002 rain event.

For further protection from debris flows, steel debris racks, constructed from 15-cm -diameter (6-in-diameter) steel pipe, were installed; three in Knight Canyon and two in South Drainage, which drains into the spillway area directly downstream from the dam. These impressive structures (Photos 4 and 5) were anchored in concrete below ground, and extended above ground, 1 to 2 m (6 to 7 ft). A Vibro-Hammer attached to a Trac-Hoe was used to install the structures.

Photos 4 and 5. Debris Rack in South Canyon holding back debris after September 2002 rain event.



Photos 6 and 7. LEBs constructed in the area around Knight Canyon.

As an additive measure to prevent debris from entering the spillway, a 213-m-long (700-ft-long) bypass channel was constructed and concrete jersey barriers were installed above the spillway area.

In the Knight Canyon and South Drainage, LEBs were constructed on over 93 ha (231 ac) (Photos 6 and 7). Like many other rehabilitation measures on this project, the LEBs exceeded the accepted government specifications; from 200 to 625 per ha (80 to 250 per ac) were constructed (compared to government specifications which call for 75 to 100 per ha [30 to 40 per ac]).

The final measure to be implemented was perhaps the most rigorous and demanding aspect of the entire project—seeding, mulching, and crimping the burned area in and above the two canyons. Over 172 metric tons (190 tons) of straw mulch was spread and imbedded into the soil, all accomplished with manpower alone. Approximately 100 ha (250 ac) have been replanted to date. In addition, thousands of seedlings have been planted in the burn area around the reservoir.

Implementation of these measures, many by hand, was only the starting point of watershed rehabilitation. FWCD initiated a rigorous maintenance, repair, and replacement program for BMPs in the watershed. FWCD had periodically removed sediment from LEBs, detention areas and check structures. Revegetation has been closely monitored and supplemented as necessary. Photo 8 illustrates the success of revegetation as of the summer of 2003.

Photo 8. Example of Revegetation Success.

By the end of 2004, $326,218 had been spent on rehabilitation and maintenance through the Clean Water Act Section 319 Non-point Source grant program, including non-federal match money and contributions from the Supplemental Environmental Program (SEP) grant provided by the CDPHE, all to protect the Lemon Dam facility valued at between $136 and $150 million.

Results

The Lemon Reservoir rehabilitation has been cited as a success by CDPHE, FWCD, La Plata Soil Conservation District (LPSCD), Southwestern Water Conservation District (SWCD), and numerous Florida River ditch companies. These entities heralded the project as "what has arguably become the largest and most aggressive post-fire watershed rehabilitation effort ever attempted by a local entity in La Plata County and possibly the state of Colorado (FWCD 2004)." CDPHE cited the project as a model Section 319 project. The project was awarded the 2004 Section 319 "Hall of Fame" award for moving dirt.

The effectiveness of the rehabilitation measures was truly put to the test when 2.47 inches of rain fell over a 13-hour period on the September 9, 2003 rainfall event (Photos 9 and 10). Runoff, sediment, and debris from the Knight Canyon watershed during this event were substantially less than from other comparably sized, nearby watersheds that had not received such extensive treatment. This was quantified through on-the-spot observations and photos, measurements of sediment removed from LEBs, ponds, and other BMPs following the runoff event, and calculations based on soil loss rates from burned and unburned land.

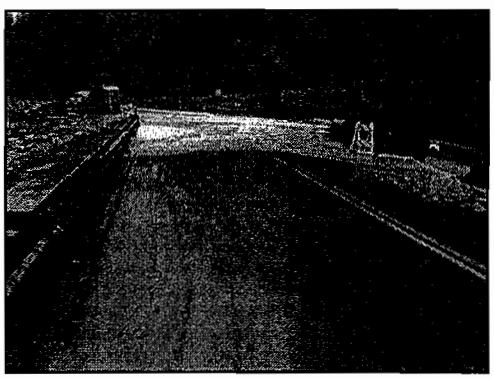


Photo 9. Weightman Canyon, September 9, 2003, Not Treated

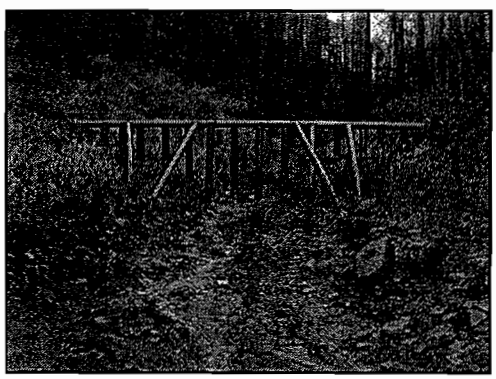


Photo 10. Knight Canyon, September 9, 2003, Treated.

The measurements of sediment removed from Pond Nos. 1, 3, and 7 (Figure 3) following the September 9, 2003 rainfall event are a testament to the effectiveness of restoration measures that were implemented in the watershed following the wildfire, including extensive seeding and crimped mulching. Observations during the runoff following the September 9, 2003 event indicated that the runoff from the burn area was relatively "clean," especially in the context of the type of runoff that is typically experienced following forest fires which is more akin to a debris flow than to runoff. To characterize the effectiveness of the measures in the watersheds relative to other untreated burned areas, WWE made the following very conservative assumptions to estimate sediment yield from the Knight Drainage:

1. Sediment volumes removed from ponds Pond Nos. 1, 3, and 7 were used as the basis for calculating sediment yields for the drainage areas above the ponds. For the analysis of sediment yield above Pond No. 1, which is on channel below the other ponds, sediment accumulation from all ponds above Pond No. 1 were also included in calculations.
2. WWE assumed a porosity/water content of sediments removed from ponds of 30 percent. In other words, every m3 (yd3) of sediment removed from a pond, consisted of 1 m3 (0.7 yd3) of sediment and 1 m3 (0.3 yd3) of pore space and/or water.
3. WWE assumed a specific gravity of 2.65 g/cm3 for sediments.
4. WWE multiplied the mass of sediment removed from the ponds by a factor of two to account for sediments in runoff that were not trapped by the pond. This corresponds to a pond efficiency of 50 percent.
5. WWE then determined sediment yield by dividing the mass of material by the area above the pond to give sediment yield in terms of metric tons of sediment per ha. To place an upper bound on sediment yield from the watershed, WWE multiplied the yield determined from the sediments removed after the September 9, 2003 event by a factor of five. This is a very conservative assumption, essentially assuming that five events of the magnitude of the September 9, 2003 event occur in a single year.

The results of these calculations are shown in Table 5, in which the estimated maximum annual sediment yields summarized demonstrate excellent effectiveness of restoration efforts in the watershed. Peter Robichaud of the United States Department of Agriculture (USDA) Forest Service, a well-known researcher on hydrologic and sediment delivery effects of wildfires in the west reports typical sediment yield rates following wildfires ranging from 3 to 20 ha/ac/yr (9 to 49 tons/ac/yr) (Robichaud 2000). By comparison, the soil loss rates for the Knight Drainage are amazingly low.

Water quality samples from the South Drainage, Knight Canyon, the Florida River, and Weightman Canyon were collected and analyzed. Results of these analyses show the BMPs have been effective, with total suspended solids (TSS) averages for Weightman, Knight, and South Drainages of 5,432, 1,655, and 14,371 milligrams per liter, respectively.

TABLE 5
MAXIMUM ANNUAL SEDIMENT YIELD ESTIMATES FOLLOWING THE MISSIONARY RIDGE WILDFIRE[1]

Pond	Estimated Maximum Annual Sediment Yield for Watershed above Pond (metric tons per ha per year/ tons per acre per year)
No. 1	0.13/0.14
No. 3	0.09/0.10
No. 7	0.06/0.07

[1] For the Knight Drainage Watershed, based on sediments removed from ponds.

Conclusion and Lessons Learned

1. The implementation of BMPs immediately after the fire when the hydrophobicity of the soils is greatest was an important component of the program. Clearing debris from the channels, installation of detention basins, LEBs, and debris racks before large rainstorm events in August and September greatly reduced post fire stormwater runoff during periods when the soils hydrophobicity and related runoff was highest.
2. Early on the ground coordination with funding entities (NRCS, Bureau of Reclamation, CDPHE), environmental regulators (USACE, NFS, State Forest Service), and private landowners proved very helpful with both funding the work and avoiding conflicts with environmental regulations and private landowner interests.
3. Using a multi-pronged approach including a diverse array of BMPs was imperative to the success of the program. The coordination of sawyers to salvage burned trees (salvaged loggers) and install LEBs, aerial and hand application of seed, debris removal from channels and the installation of debris racks and detention basins, and mulching, including hand crimping, all lead to the success of reducing soil loss.
4. Crimping the mulch by driving the mulch by hand into the soils was important, as very little straw mulch was lost from wind and runoff, and allowed for the successful use of straw mulch on steeper slopes.
5. Maintenance of the BMPs after installation was a major factor in the success of the program. LEBs were continually reconstructed, and the soil that accumulated behind each LEB was removed, thus creating basins behind the LEBs. The ongoing maintenance of the LEBs, including deposited soil removal, is instrumental even today in reducing the soil loss in the basin. Overall, the crew has reconstructed 223 ha (550 ac) of LEBs. Furthermore, the maintenance program includes cleaning out debris racks, detention basins, and spot reseeding and remulching throughout the project area.

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